AFRL-RX-WP-JA-2016-0271

DNA-NUCLEOBASES: GATE DIELECTRIC/ PASSIVATION LAYER FOR FLEXIBLE GFET-BASED SENSOR APPLICATIONS (POSTPRINT)

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22 JULY 2015
Interim Report

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AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
22 July 2015	Interim	8 September 2014 – 22 June 2015

4. TITLE AND SUBTITLE
DNA-NUCLEOBASES: GATE DIELECTRIC/ PASSIVATION LAYER FOR FLEXIBLE GFET-BASED SENSOR APPLICATIONS (POSTPRINT)

5a. CONTRACT NUMBER
FA8650-15-D-5405-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62102F

6. AUTHOR(S)
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(continued on pg. 2)

5d. PROJECT NUMBER
4348

5e. TASK NUMBER 0001

5f. WORK UNIT NUMBER
X0YC

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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(continued on page 2)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Materials and Manufacturing Directorate
Wright-Patterson Air Force Base, OH 45433-7750
Air Force Materiel Command
United States Air Force

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/RXAS

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RX-WP-JA-2016-0271

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES
PA Case Number: 88ABW-2015-3728; Clearance Date: 24 Sep 2015. This document contains color. Journal article published in Proc. SPIE 9557, Nanobiosystems: Processing, Characterization, Vol. 9557, 24 Sep 2015. © 2015 SPIE. The U.S. Government is joint author of the work and has the right to use, modify, reproduce, release, perform, display, or disclose the work.
The final publication is available at http://spiedigitallibrary.org http://dx.doi.org/10.1117/12.2190913

14. ABSTRACT ***(Maximum 200 words)***
The main goal of this research was to maintain the bulk charge carrier mobility of graphene, after deposition of the gate dielectric layer used for making transistor devices. The approach was introducing a thin film of deoxyribonucleic acid (DNA) nucleobase purine guanine, deposited by physical vapor deposition (PVD), onto layers of graphene that were transferred onto various flexible substrates. Several test platforms were fabricated with guanine as a standalone gate dielectric, as the control, and guanine as a passivation layer between the graphene and PMMA. It was found that the bulk charge carrier mobility of graphene was best maintained and most stable using guanine as a passivation layer between the graphene and PMMA. Other transport properties, such as charge carrier concentration, conductivity type and electrical resistivity were investigated as well. This is an important first step to realizing high performance graphene-based transistors that have potential use in bio and environmental sensors, computer-processing and electronics.

15.
Computing systems; Electronics; Environmental sensing; Graphene; Physical vapor deposition; Sensors; Thin films;

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor) / 19b. TELEPHONE NUMBER *(Include Area Code)*
Unclassified	Unclassified	Unclassified	SAR	9	Lawrence Brott / (937) 255-9157

REPORT DOCUMENTATION PAGE Cont'd

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Invited Paper

DNA-nucleobases: Gate Dielectric/Passivation Layer for Flexible GFET-based Sensor Applications

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Abstract

The main goal of this research was to maintain the bulk charge carrier mobility of graphene, after deposition of the gate dielectric layer used for making transistor devices. The approach was introducing a thin film of deoxyribonucleic acid (DNA) nucleobase purine guanine, deposited by physical vapor deposition (PVD), onto layers of graphene that were transferred onto various flexible substrates. Several test platforms were fabricated with guanine as a standalone gate dielectric, as the control, and guanine as a passivation layer between the graphene and PMMA. It was found that the bulk charge carrier mobility of graphene was best maintained and most stable using guanine as a passivation layer between the graphene and PMMA. Other transport properties, such as charge carrier concentration, conductivity type and electrical resistivity were investigated as well. This is an important first step to realizing high performance graphene-based transistors that have potential use in bio and environmental sensors, computer-processing and electronics.

Introduction

Two test platforms that could be used as potential applications for biosensing and electronics were fabricated. In the first test platform, guanine was used as a gate insulator in a graphene field effect transistor (GFET) configuration, whereas in the second test platform guanine was used as the "passivation layer" on top of the graphene layer, between the graphene and PMMA. Deposition techniques and various substrates comparing standalone charge carrier mobility with mobility with the gate dielectric were studied. This work used solvent-less PVD to minimize the use of environmentally unfriendly solvents. The substrate-graphene and graphene-dielectric interfaces were studied to observe the effects of environmental conditions, such as fluctuations in temperature, humidity and oxygen levels in the atmosphere. In microfluidics, the integration of graphene as a "lab on a chip" in the fabrication of a biosensor could be used for human performance monitoring and/or enhancement (sweat monitoring).

Graphene field effect transistors exhibit several electrical characteristic properties. Graphene has a zero band gap (Avouris 2012). The current in a graphene channel does not close completely; the gate limits the current on/off ratio of ~104. With a high carrier mobility and mechanical, electrical stability of the material, graphene is an ideal candidate for a field-effect transistor (Avouris 2012).

1. Experimental

Monolayers of graphene were grown on Cu foil by CVD and then transferred onto thermal release (TR) tape. The monolayers of graphene were transferred (i.e. rolled) onto different flexible substrates to determine the flexible substrate to be used in the bio-based graphene/dielectric test platform. Layers of 1, 2, and 4 monolayers were transferred onto these flexible substrates. The flexible substrates that were studied were kapton, Polydimethylsiloxane (PDMS), photo-print paper (laminate side) and Corning Willow glass (WG). Guanine was deposited onto graphene that had been transferred onto the rigid and flexible substrates by way of physical vapor deposition (PVD).

Nanobiosystems: Processing, Characterization, and Applications VIII, edited by Norihisa Kobayashi, Fahima Ouchen, Ileana Rau, Proc. of SPIE Vol. 9557, 95570I · © 2015 SPIE · CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2190913

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An investigation into flexible substrates-kapton, PDMS, photo-print paper, and WG were performed to determine whether the graphene-substrate interface effects the graphene properties (i.e. charge carrier mobility, resistivity and charge carrier concentration) (Williams et al. 2013).

Here, 4-MLG was transferred onto flexible substrates-kapton, PDMS, photo-print paper, and WG. Kapton, PDMS, and photo-print paper were chosen as flexible substrates due to their availability and low cost. On the other hand, WG was chosen for its' availability *only*.

2. Results and Discussion

Studies of 4-MLG on kapton and PDMS resulted in inconsistent charge carrier mobilities and open circuits on the graphene-based samples. Photo-print paper had surface adhesion issues between the graphene-laminate surfaces (Williams et al. 2014). The most suitable flexible substrate appeared to be WG with consistent and reproducible graphene charge carrier mobilities (Williams et al. 2015).

Table I. Initial studies of four monolayers of graphene flexible substrates (Williams et al. 2015)

Substrate	Charge Carrier Mobility (cm^2/Vs)	Yield of Usable Sample (%)
Kapton	**273 ± 235**	**50**
Photo-Print Paper	**38**	**16**
PDMS	**0**	**0**
Willow Glass	**530 ± 342**	**100**

Two test platforms were fabricated for comparison of the dielectric properties of guanine and PMMA at thicknesses of 60 nm, 300 nm, and 1 µm thick. The first test platforms had either guanine only, or PMMA only, on top of 4-MLG onto WG substrate. Dielectric thicknesses below 60 nm proved too thin and produced non-uniform thin films. Therefore, 60 nm, 300 nm and 1 µm thicknesses were chosen and uniformity was studied. Graphene was the back electrode in both configurations. In fig. 1, guanine was used as a dielectric material deposited onto graphene monolayers (Williams et al. 2014).

In fig. 2, guanine was a passivation layer (e.g. a hermetic seal) to preserve graphene's transport properties. Monolayers of graphene (MLG) were stacked on top of each other on the surface of the WG substrate.

After deposition of PMMA onto 4-MLG decreased graphene bulk mobility 29.2% and 15.6%. After deposition of guanine onto 4-MLG decreased graphene bulk mobility 2.55% and 0.75%.

Charge carrier mobilities were then studied for test platform B-60 nm PMMA/10 nm guanine/4-MLG/WG to determine if this test platform is stable at RT in air for up to 6 days. The "control" mobility of this batch had a charge carrier mobility of 812 cm^2/Vs. All 3 samples were derived from the same batch of graphene. These data show that the test platform with PMMA as the dielectric layer and guanine as the passivation layer maintains the standalone mobility of graphene over a period of 6 days in air at RT. These results are shown in fig. 4.

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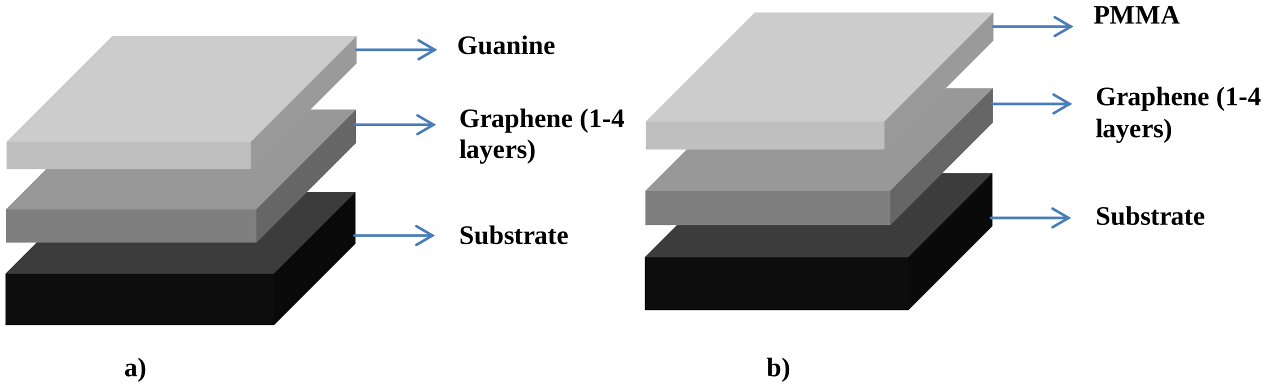

Figure 1. Schematic of graphene test platform A a) with guanine as dielectric layer and b) PMMA as dielectric layer (Williams et al. 2015).

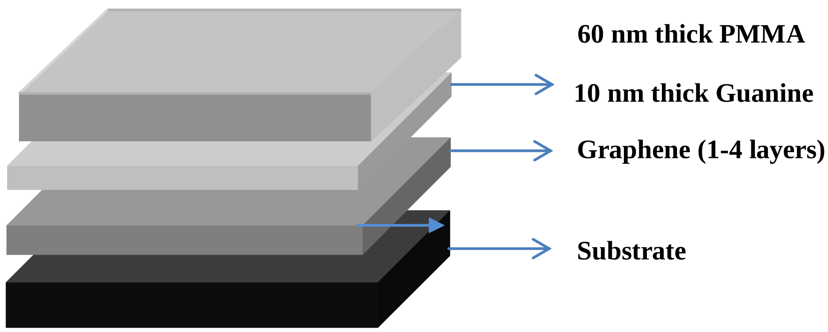

Figure 2. Schematic of graphene test platform with guanine as passivation layer and PMMA as dielectric layer (Williams et al. 2015).

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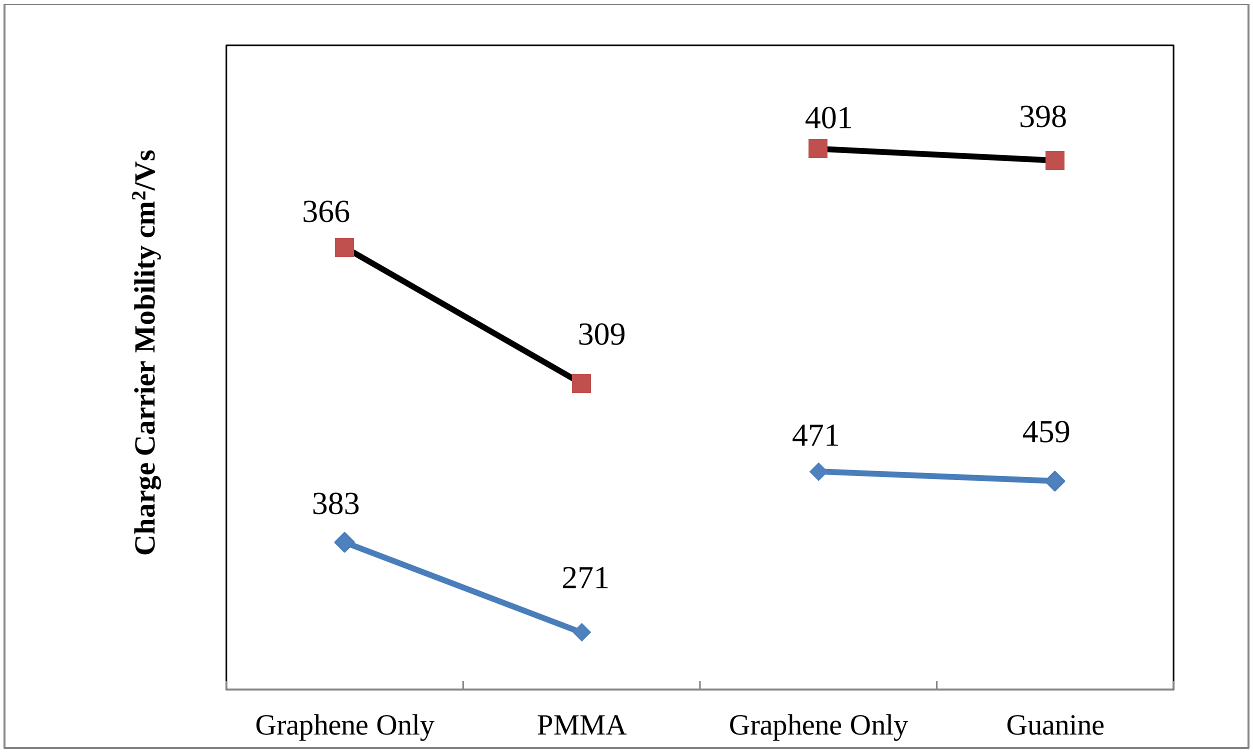

Figure 3. Electrical characterization of Graphene only and with PMMA on Graphene vs. Graphene only and with Guanine on Graphene.

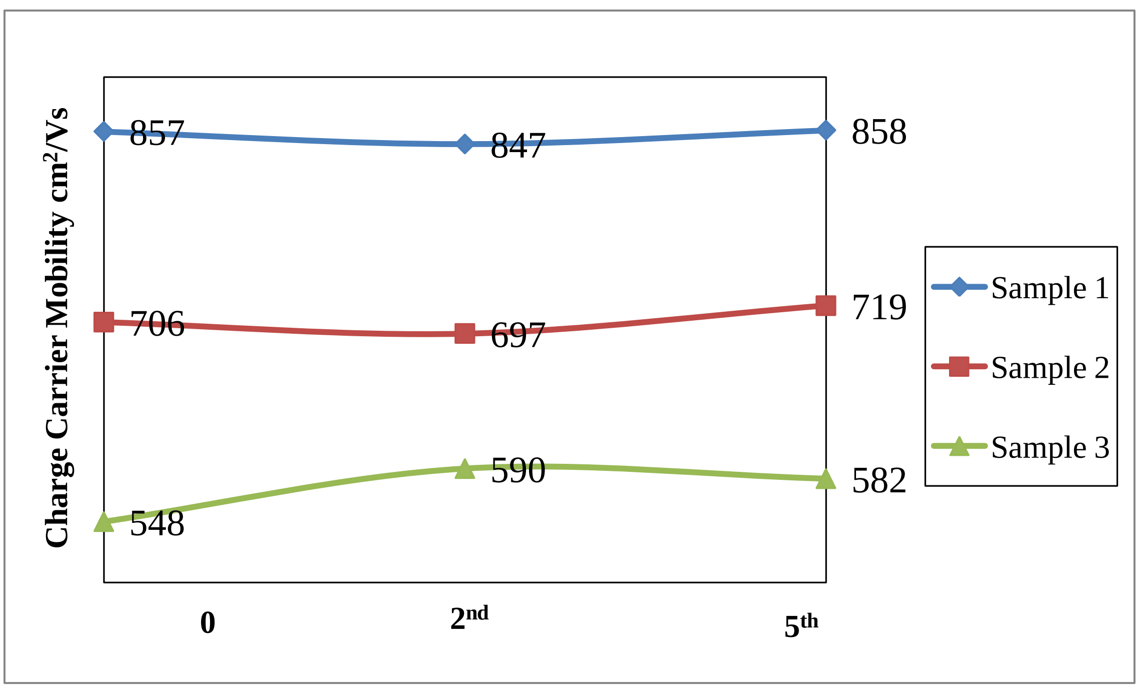

Figure 4. Bulk charge carrier mobility for up to 6 days at RT in air of Test platform B-60 nm PMMA/10 nm guanine/4-MLG/WG.

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In fig. 5, I-V measurements for test platform 1a (1 µm guanine/4-MLG/WG) and test platform in fig. 2 (60 nm PMMA/10 nm guanine/4-MLG/WG) were performed to measure leakage currents under typical DC voltage used for OFETs. In this configuration, graphene is used as the bottom electrode and Au as the top electrode.

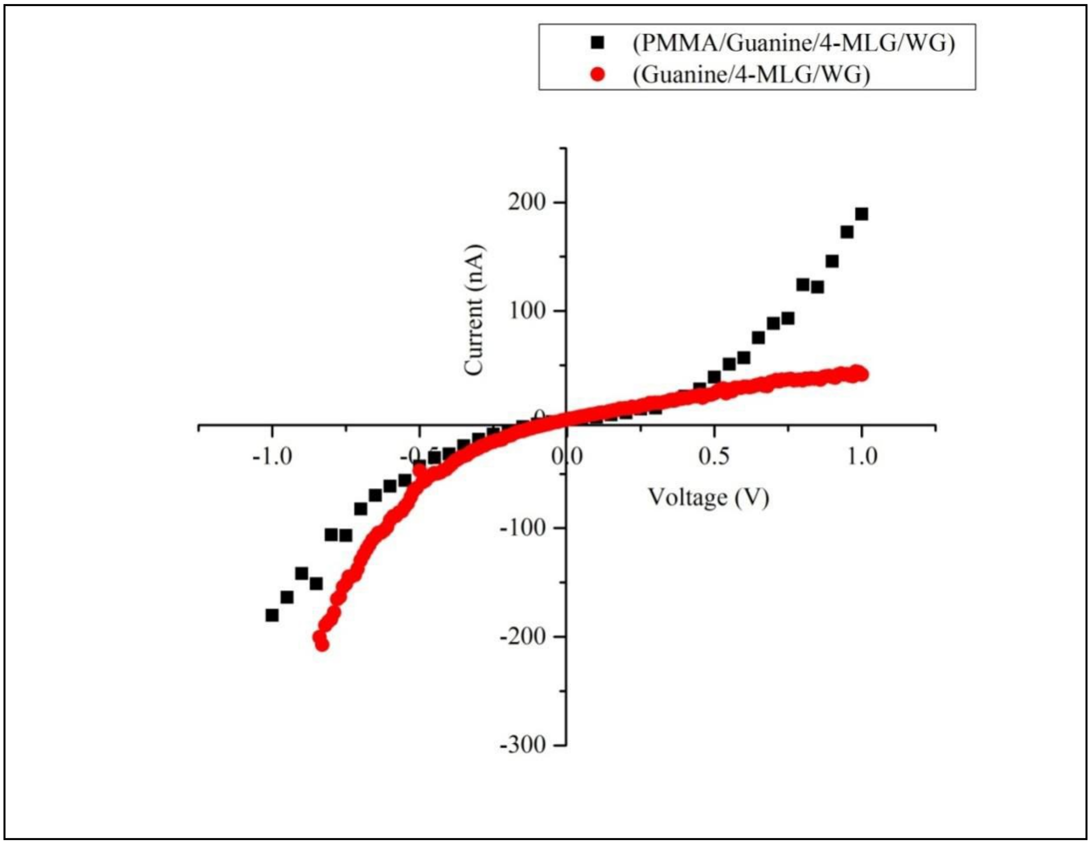

Figure 5. I-V curves for guanine as a dielectric material vs. guanine as a passivation layer.

3. Summary

In test platforms A and B, the electrical properties of graphene were maintained at 6 days, as seen previously in non-flexible and flexible substrates, with guanine as a dielectric and passivation layer. In test platform A, there was a greater decrease in graphene's electrical properties. In test platform 1b, guanine was used as a passivation layer and PMMA as the dielectric material. This agrees with the findings of test platform B. I-V curves for graphene, with guanine as the passivation layer and PMMA as the dielctric, show a less conductive layer with no shorting through the PMMA at lower voltages. In test platform A, guanine had a higher leakage current and low resistivity, due to it not being a good insulator. In contrast, guanine as a passivation layer in test platform B has a low leakage current with a high resistivity. More work is needed.

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Acknowledgments

The authors thank the US Air Force Research Laboratory and the Air Force Office of Scientific Research for their support of this study. Acknowledgment is also due to Gerald Landis for his support with substrate preparations.

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